



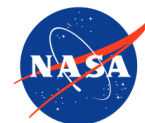
2018 International Conference on Thermoelectrics

RTGS: THE ENDURING AND THE FUTURE

David Woerner

Pre-decisional information for planning and discussion only

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Jet Propulsion Laboratory
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Large, strategic NASA missions

A recent report, by the US National Academy of Sciences, Engineering, and Medicine, entitled, *Powering Science: NASA's Large Strategic Science Missions* (2017), asserted,

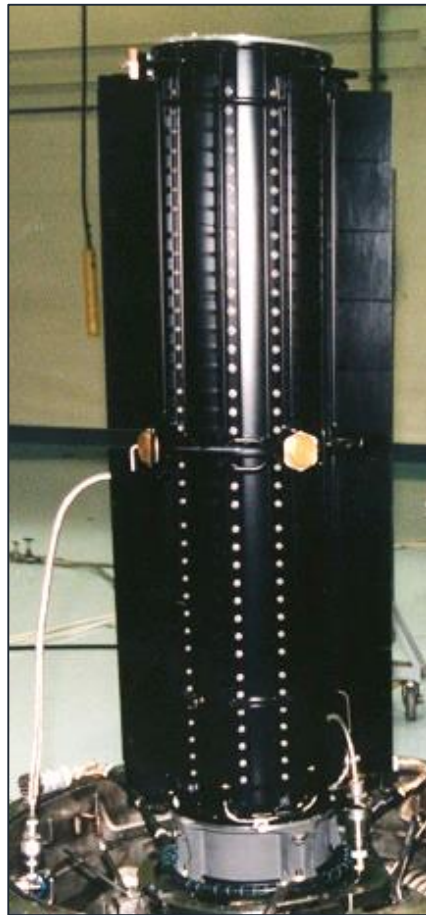
“Large, strategic missions “produce tremendous science returns and are a foundation of the global reputation of NASA and the U.S. space program.”



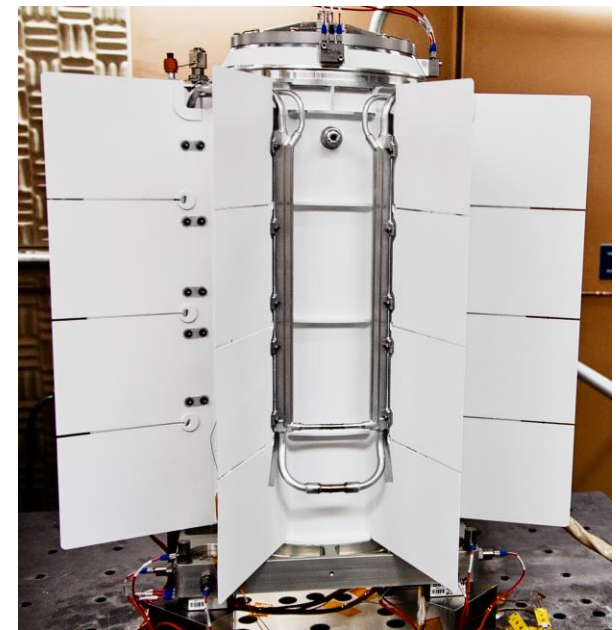
- Used by NASA missions of various types for over 50 years
 - Pioneer
 - Viking
 - Voyager
 - Galileo
 - Ulysses
 - Cassini
 - Pluto New Horizons
 - Curiosity



Multi-Hundred Watt –
Radioisotope
Thermoelectric Generator
(MHW-RTG)
(Voyager)



General Purpose Heat Source –
Radioisotope Thermoelectric
Generator (GPHS-RTG)
(Galileo, Ulysses, Cassini, Pluto
New Horizons)



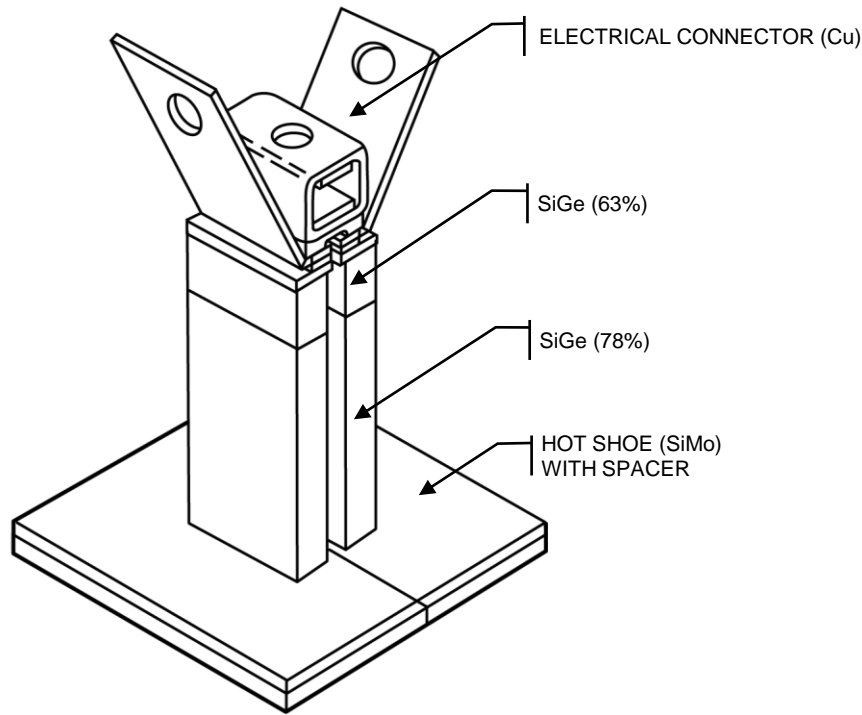
Multi-Mission Radioisotope
Thermoelectric Generator (MMRTG)
(Curiosity)

- NASA was flying 11 RTGs if you count the recently ended Cassini mission
 - Voyager, 3 MHW RTGs/spacecraft
 - Cassini, 3 GPHS-RTGs
 - PNH, 1 GPHS-RTG
 - Curiosity, 1 MMRTG

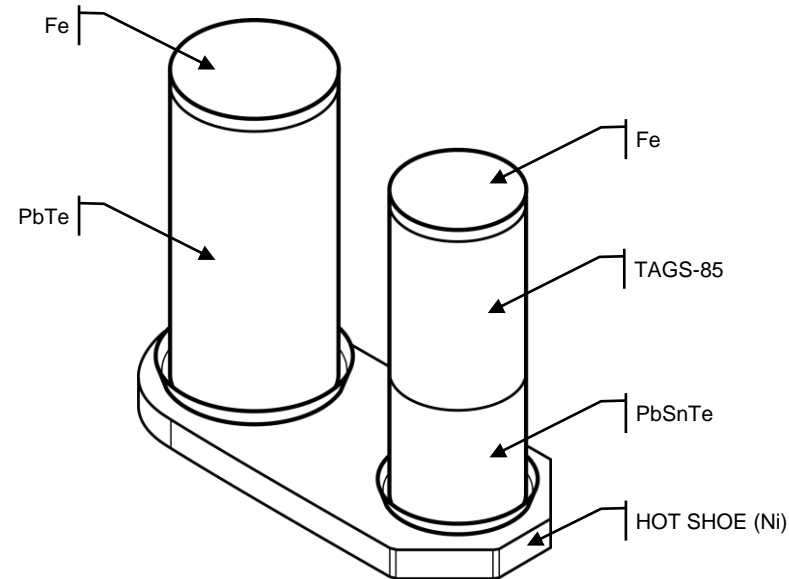
Multi-Hundred Watt –
Radioisotope
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(*Voyager*)

General Purpose Heat Source –
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(Galileo, Ulysses, Cassini, *Pluto*
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Multi-Mission Radioisotope
Thermoelectric Generator (MMRTG)
(*Curiosity*)



Silicon-Germanium Unicouple

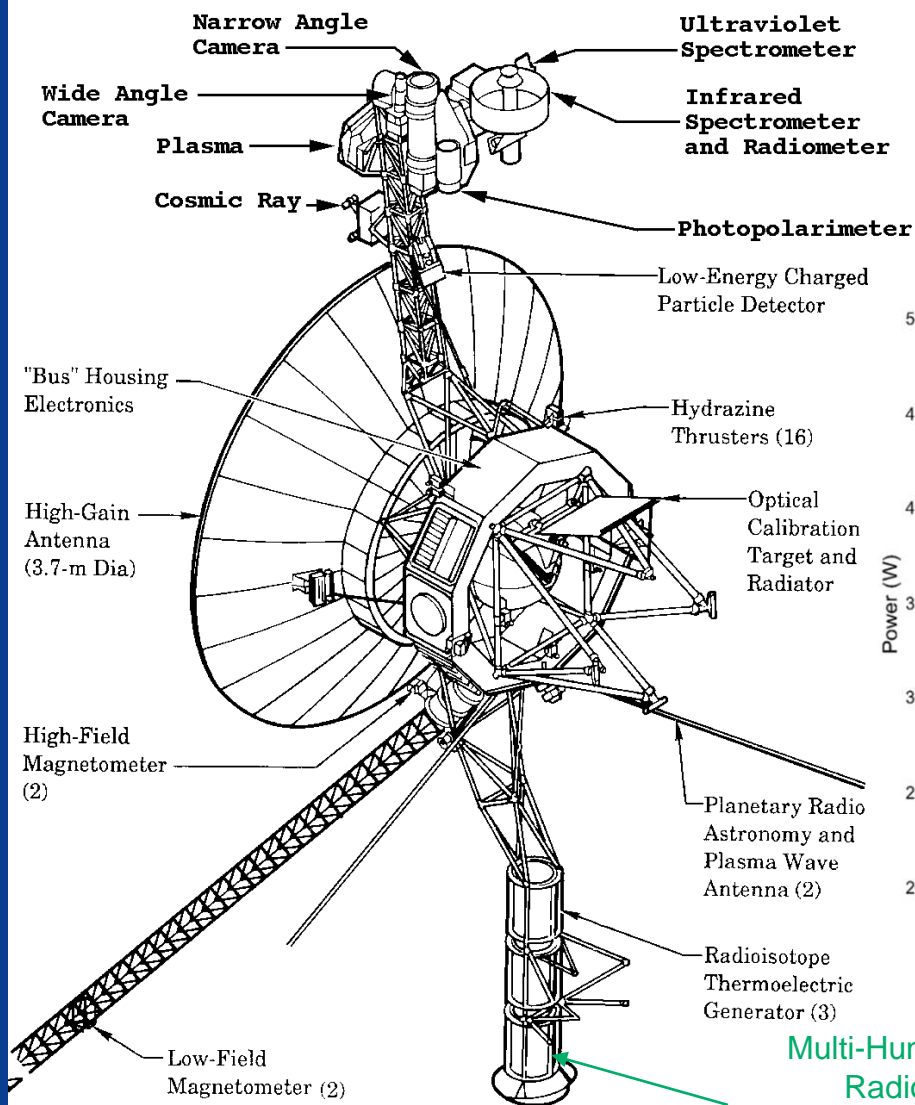


Lead-Telluride-TAGS Unicouple



Voyager 1 and 2

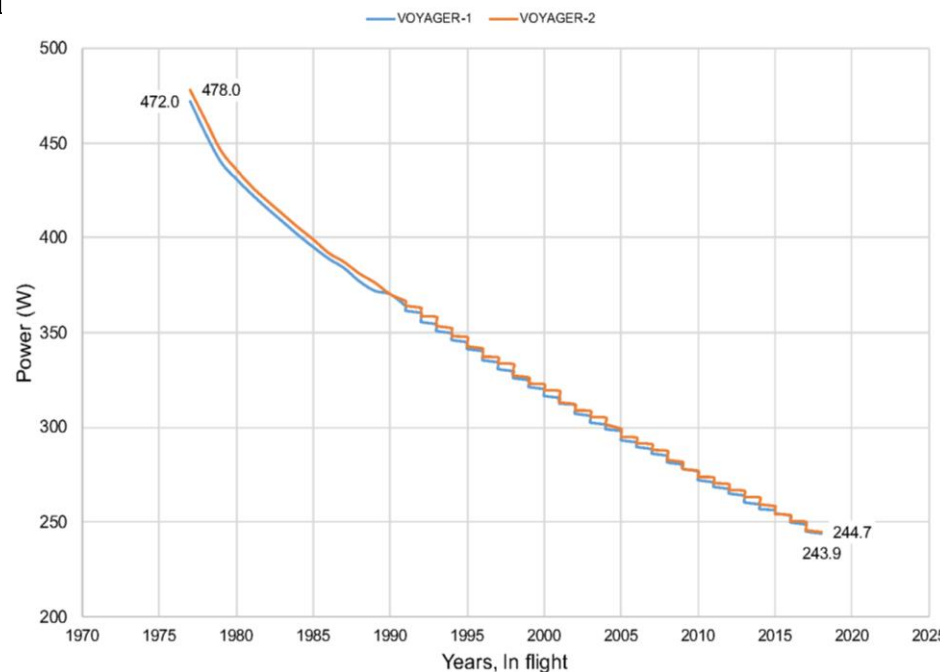
The enduring



(Spacecraft Shown Without Thermal Blankets for Clarity)

Multi-Hundred Watt –
Radioisotope
Thermoelectric Generator
(MHW-RTG)

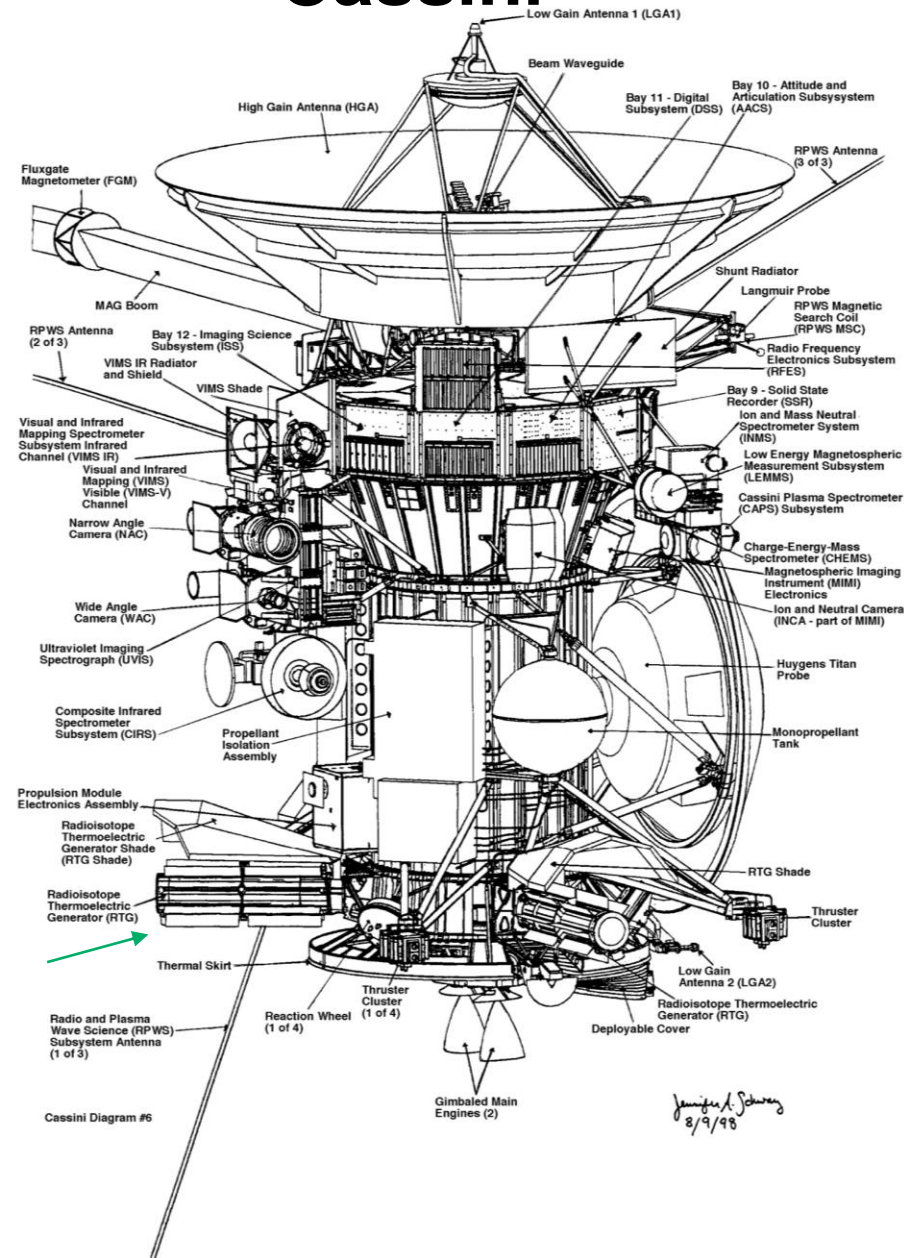
Voyager Power Output



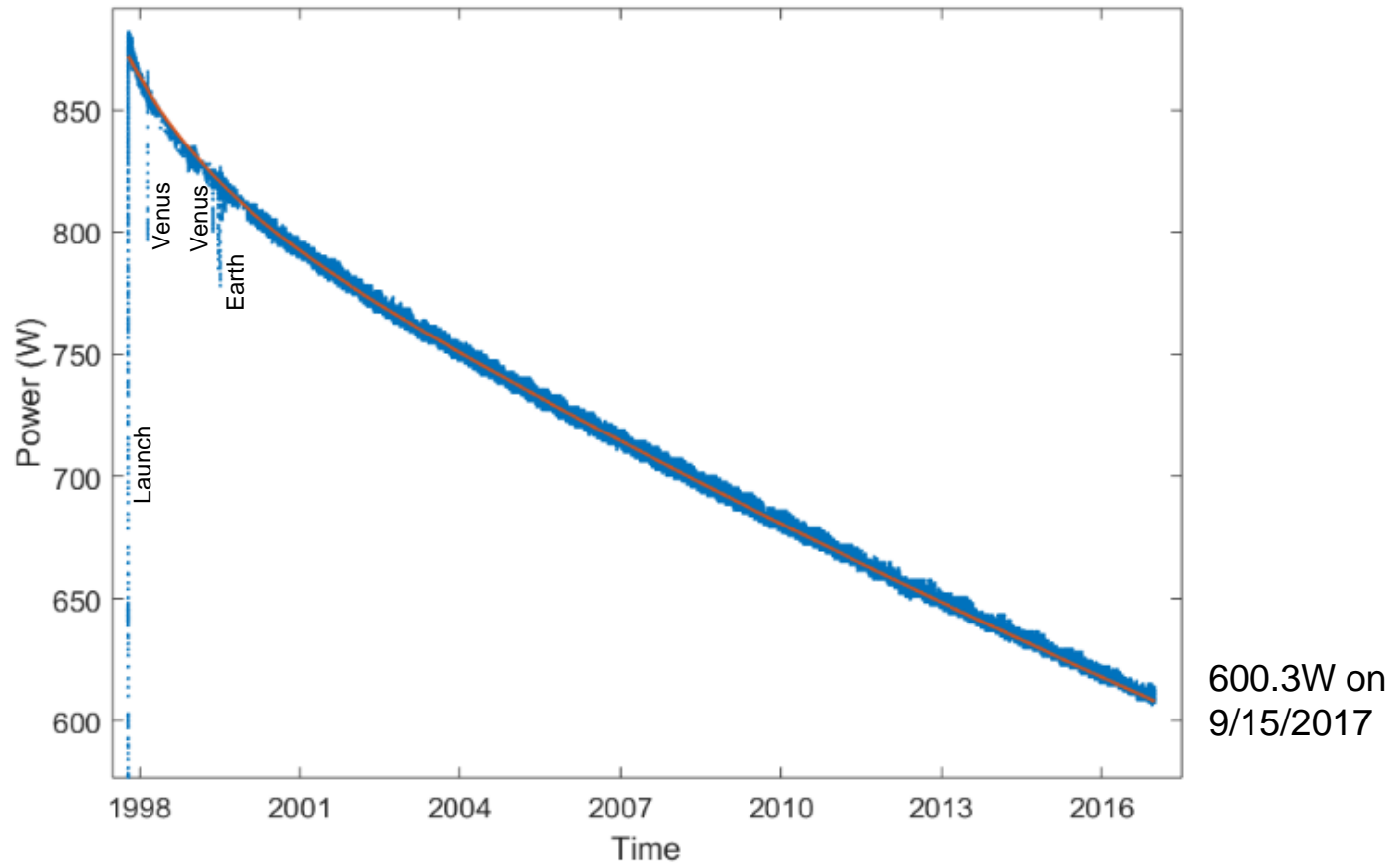
jpl.nasa.gov

Cassini

General Purpose Heat
Source – Radioisotope
Thermoelectric Generator
(GPHS-RTG)



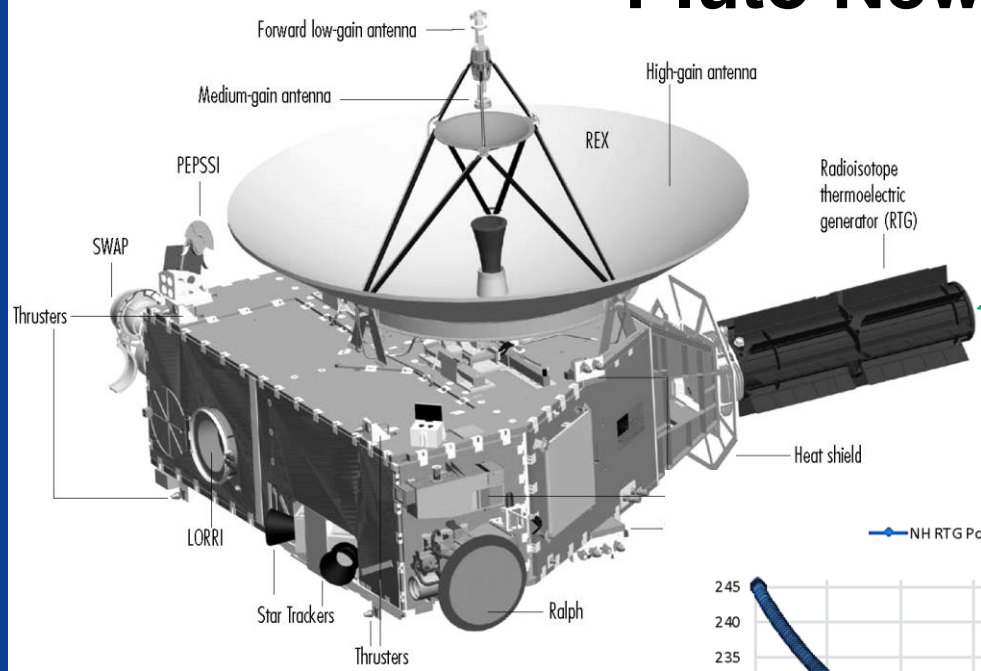
Cassini



Complete Cassini telemetry data between launch and 12/31/2016

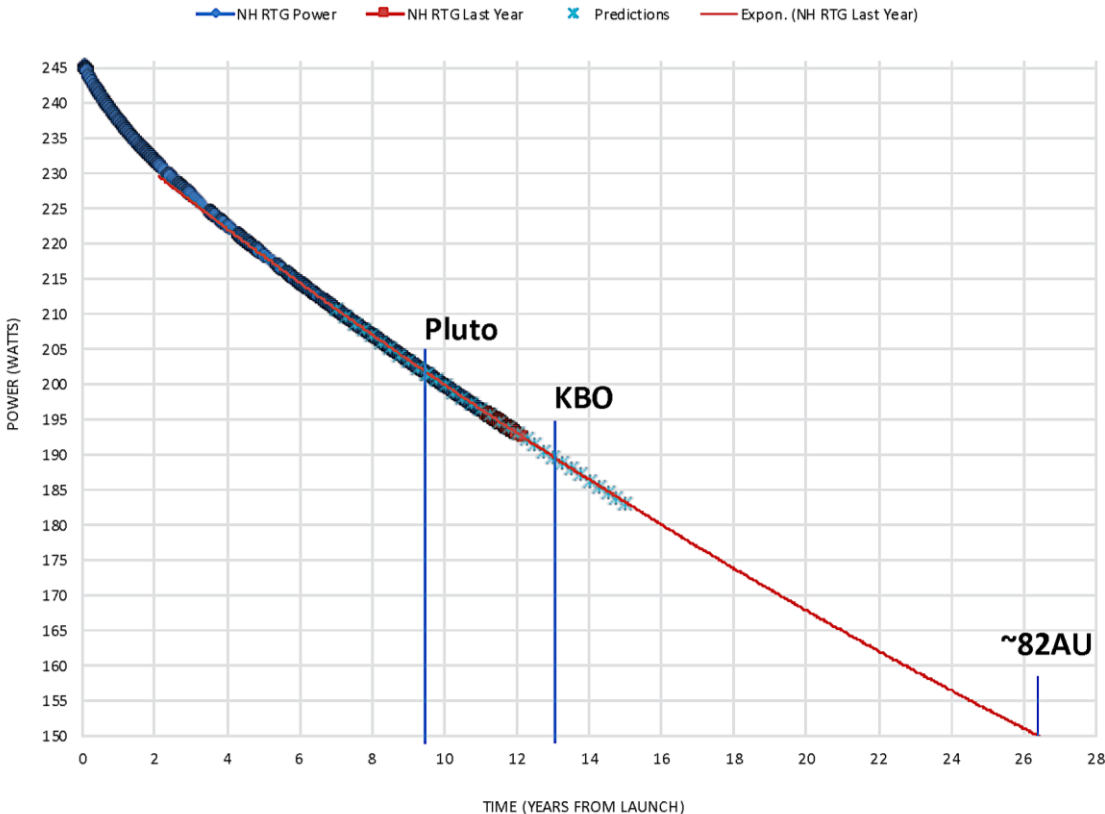


Pluto New Horizons

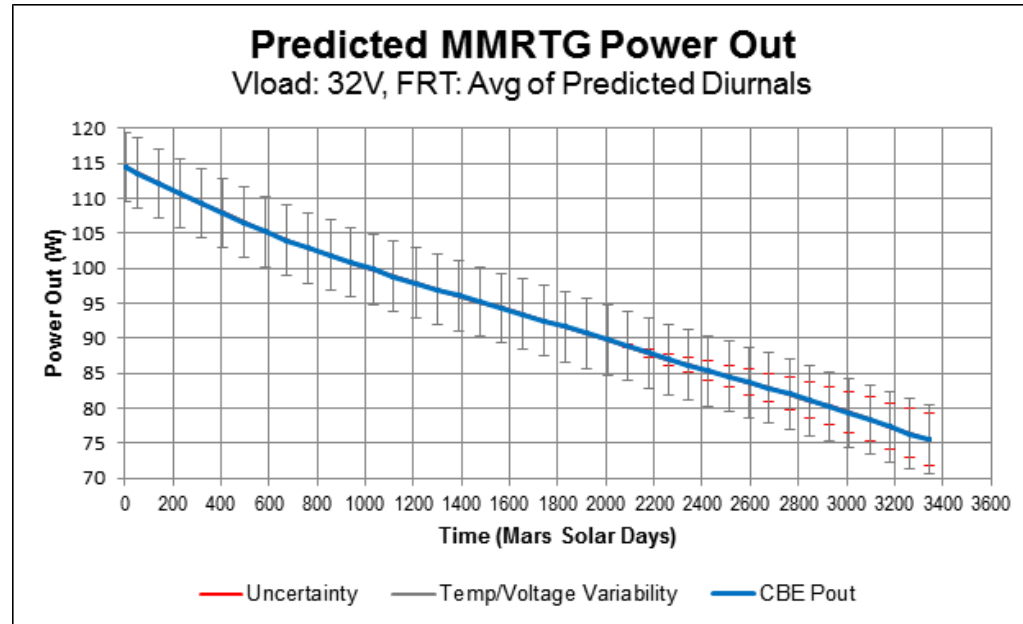
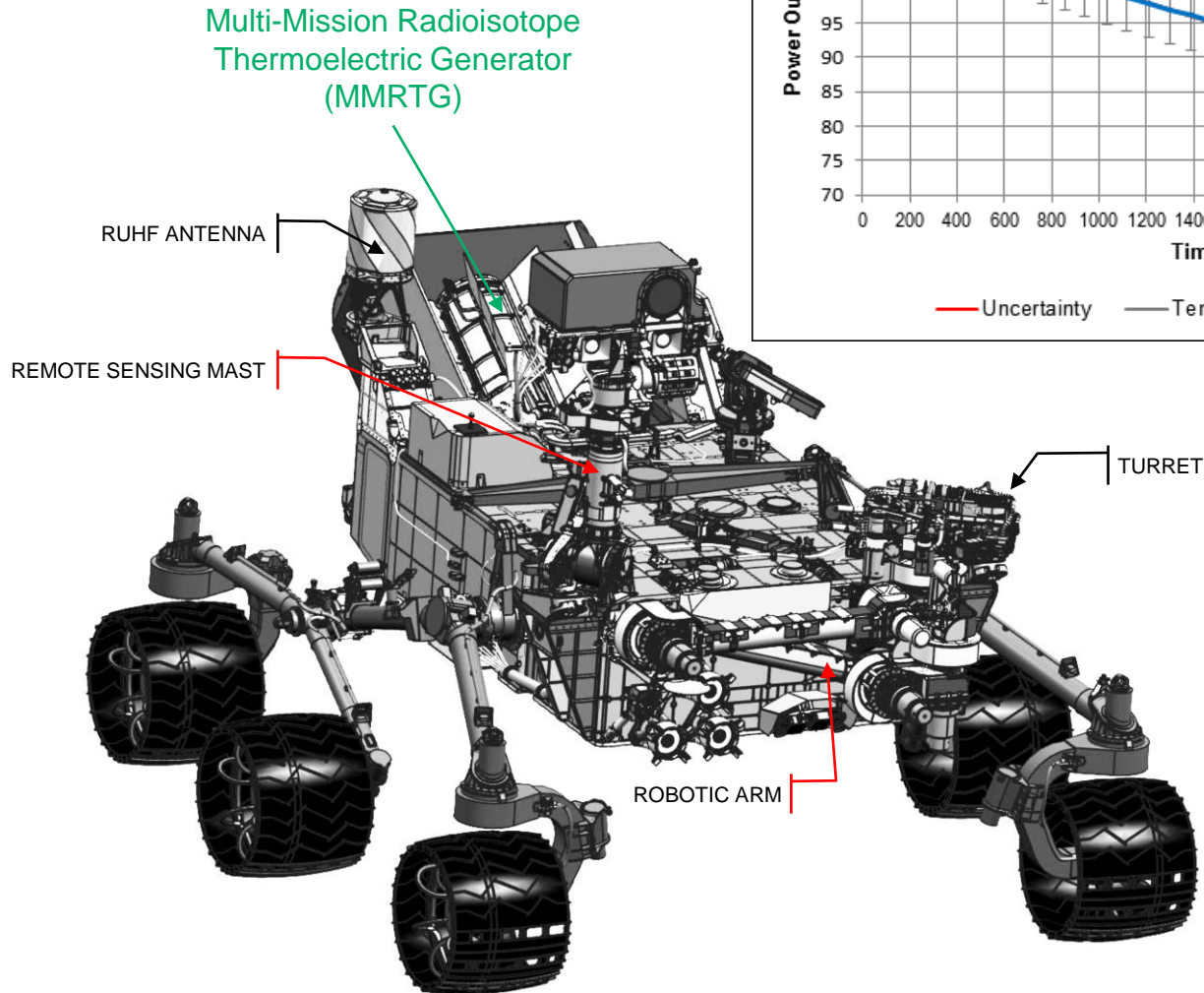


General Purpose Heat Source
– Radioisotope Thermoelectric
Generator (GPHS–RTG)

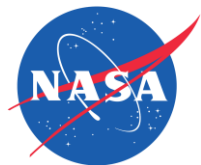
RTG OUTPUT POWER PREDICTION



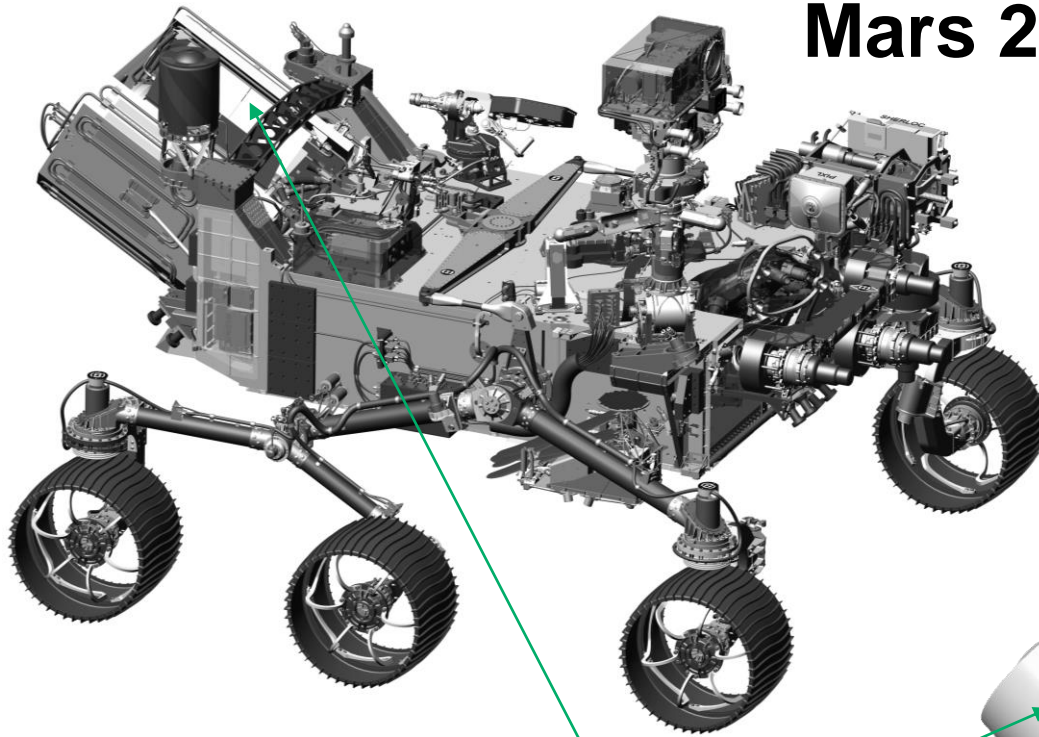
Curiosity



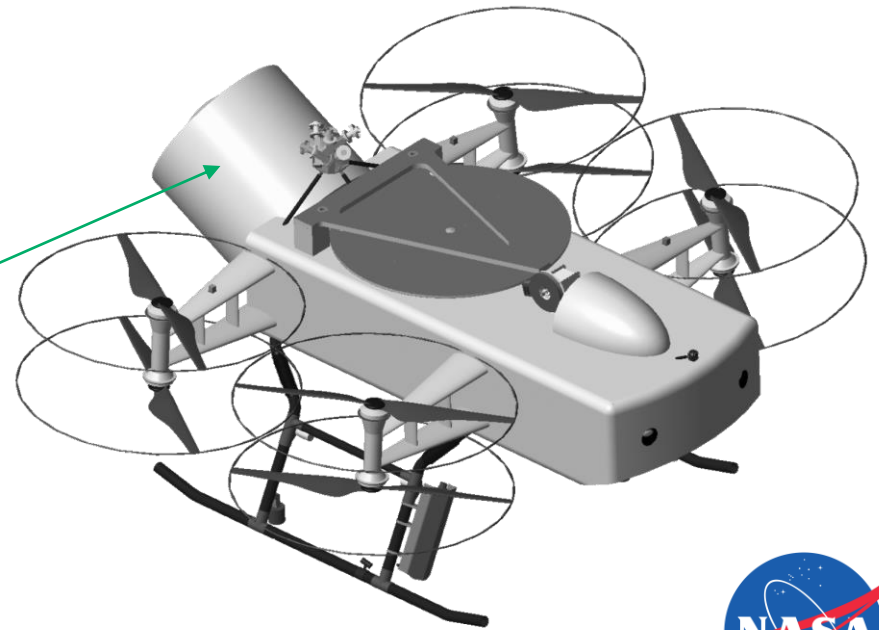
The Future



Mars 2020 (Mars)



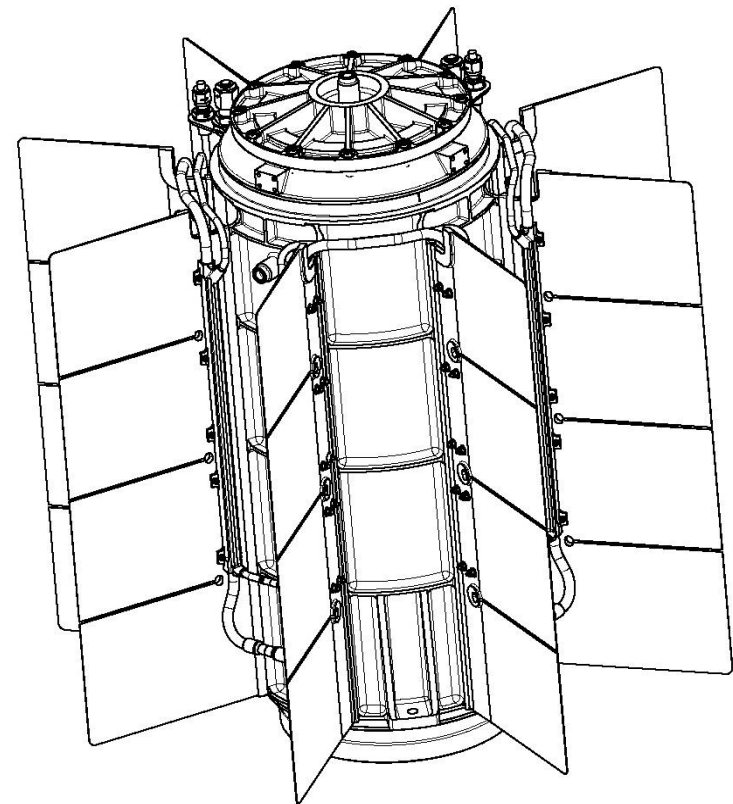
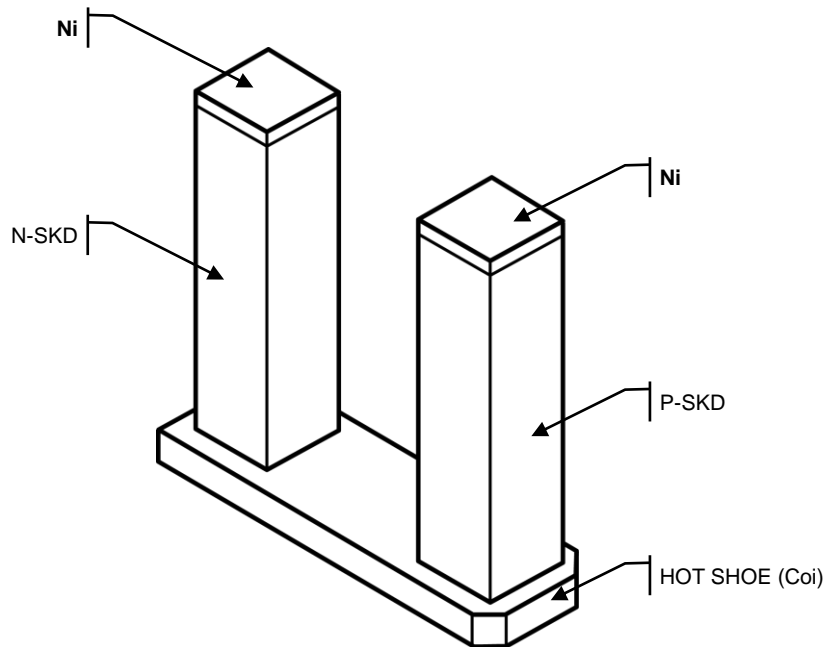
Multi-Mission Radioisotope
Thermoelectric Generator
(MMRTG)



Discovery Mission Concept: Dragonfly (Titan)



The potential enhanced MMRTG



Enhanced Multi-Mission
Radioisotope
Thermoelectric Generator
(eMMRTG)



The potential enhanced MMRTG

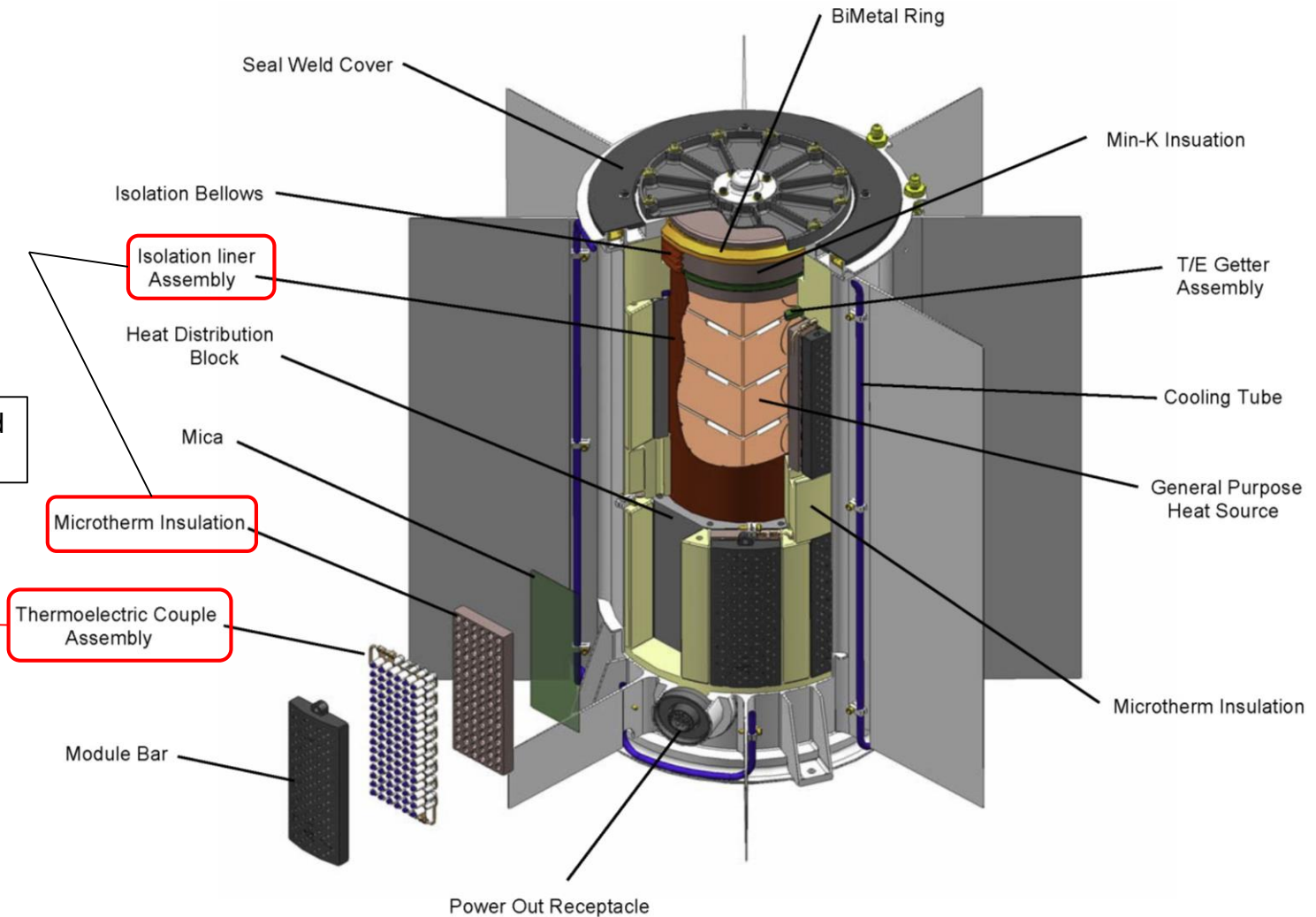
Engineering:
Emissivity
change to liner,
substitute
insulation



Changes needed
to MMRTG



New Technology:
Substitute SKD
thermoelectric
couples, module
insulation



 Enhancements

The Next-Generation RTG Study

Study Lead: David Woerner

Brian	Bairstow	JPL	Mike	Amato	GSFC	Amee	Bogner	GRC
Dan	Berisford	JPL	David	Batchelor	GSFC	Elizabeth	Turnbull	GRC
Pradeep	Bhandari	JPL	Bob	Beaman	GSFC	Evan	Roelke	GRC
Chester	Borden	JPL	Porfy	Beltran	GSFC	James	Fittje	GRC
Sevan	Chanakain	JPL	Kim	Brown	GSFC	Jeff	Woytach	GRC
Alan	Didion	JPL	Jacob	Burke	GSFC	John	Gyekenyesi	GRC
Fivos	Drymiotis	JPL	Jacob	Englander	GSFC	June	Zakrajsek	GRC
John	Elliot	JPL	Matthew	Garrison	GSFC	Justin	Walsh	GRC
Jean-Pierre	Fleurial	JPL	John	Godfrey	GSFC	Mike	Martini	GRC
Terry	Hendricks	JPL	Kyle	Hughes	GSFC	Paul	Schmitz	GRC
Insoo	Jun	JPL	Frank	Kirchman	GSFC	Robert	Jones	GRC
Reh	Kim	JPL	Jeremy	Knittel	GSFC	Steve	McCarty	GRC
Damon	Landau	JPL	Blake	Lorenz	GSFC	Steve	Oleson	GRC
Young	Lee	JPL	Paul	Mason	GSFC	Tom	Packard	GRC
Hari	Nayar	JPL	Anthony	Nicoletti	GSFC	Tom	Parkey	GRC
David	Neff	JPL	Anthony	Nicoletti	GSFC	Tony	Colozza	GRC
Arora	Nitin	JPL	Dave	Palace	GSFC	Reed	Cheryl	APL
Knut	Oxnevad	JPL	Daniel	Ramspacher	GSFC	Ken	Hibbard	APL
Martin	Ratliff	JPL	David	Robinson	GSFC	Ralph	Lorenz	APL
Timothy	Shirey	JPL	Terry	Smith	GSFC	Procktor	Louise	APL
David	Woerner	JPL	James	Sturm	GSFC	Paul	Michael	APL
Kevin	Yu	JPL				Paul	Ostdiek	APL
Chadwick	Barklay	UDRI				Ostdiek	Paul	APL
Dirk	Cairns-Gallimore	DOE				Dennis	Woodfork	APL
Steve	Johnson	DOE INL						
Tom	Spilker	Independent						

APL – Applied Physics Lab
DOE – Department of Energy
GRC – Genn Research Center
GSFC – Goddard Spaceflight Center
INL – Idaho national Lab



Next-Gen RTG Study completed in 2017

Was motivated by the need for larger RTGs than presently available or near-term improvements

- **Serve NASA for 2-3 decades** to come
- To address the needs of future Decadal Survey missions
 - ✓ An RTG that would be useful **across** the **Solar System**
 - ✓ An RTG that **maximizes** the types of **missions**: flyby, orbit, land, rove, boats, submersibles, balloons
 - ✓ An RTG that has **reasonable** development **risks** and **timeline**



Approach For The Study

GPHS-RTG
Req.

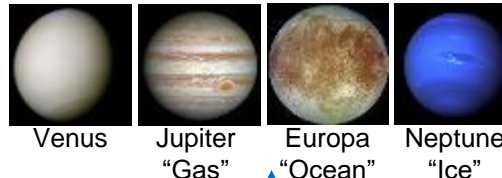


MMRTG/
eMMRTG
Req.



Destinations (63)

(Visited or suggested in Decadal Surveys)



Final report

Visit rps.nasa.gov >
Resources > Reports

RTG Concepts

- General Purpose for max. fit
- Specialized RTGs for significant niches
- Timeline

Requirements

- Performance
- Physical
- Structural
- Environmental

TE Technologies

- Literature search
- Lab data
- Screen materials
- Model couples

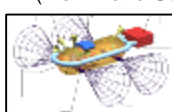
Launch Vehicles (4)

Spacecraft/Missions (99) /Mission Types

(Flown and Studied)



Cassini
(Orbiter)
"Flown"



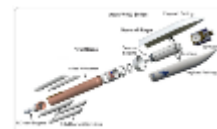
Venus Rover
(Surface)
"Suggested"



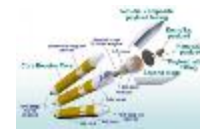
Titan Submarine
(Subsurface)
"Suggested"



Titan IV B
Launched:
Cassini



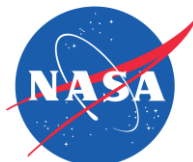
Atlas V (541)
Launched: MSL



Delta IV
Heavy
Potential
Launcher



SLS (1 A and
B)
Potential
Launcher



Thermoelectric Technology

Configuration	# Segments	~Couple Efficiency at Tcj 450K	TRL Materials n/p		TRL of Configuration	~ Generator Efficiency (16 GPHSs)
1	3 Element	17	9/2/2	9/2.5/3.5	1	14.8
2	3 Element	15	9/2/3.5	9/2.5/3.5	1	13.6
3*	3 Element	16	9/4/2	9/4/3.5	2	13.9
4*	3 Element	14	9/4/3.5	9/4/3.5	2.5	12.7
10	1 Element	14	2	3.5	2	12.1
11	1 Element	11	3.5	3.5	3.5	10
14	2 Element	14	9/2	9/3.5	2.5	12.6
21	2 Element	12	9/3.5	9/3.5	2.5	10.6

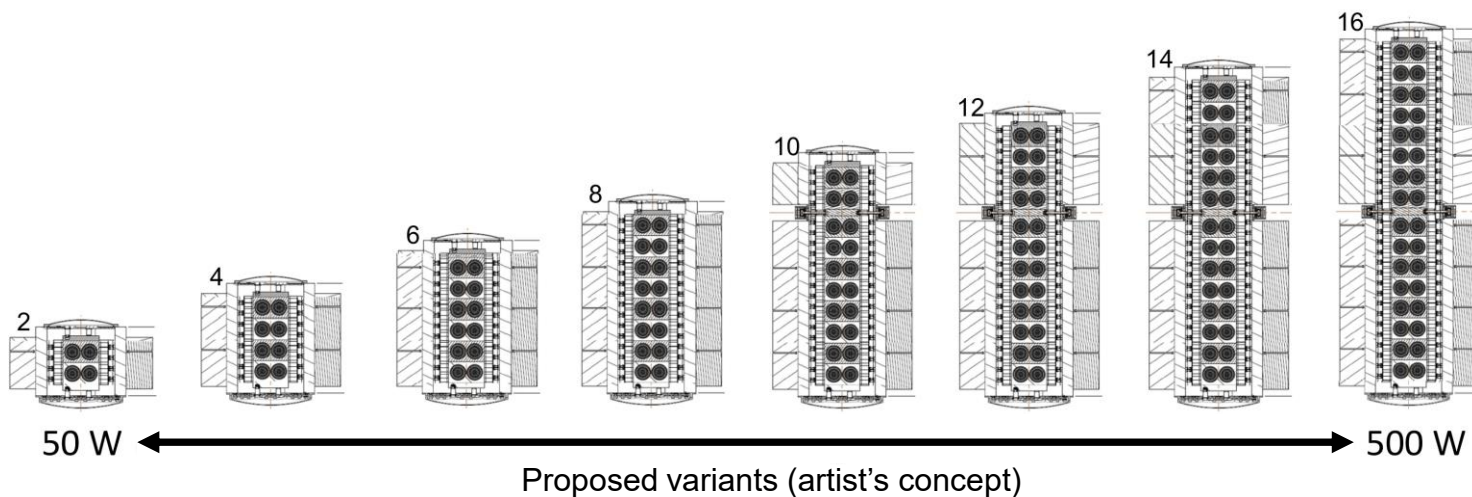
* Contains SKD

Choose ~4 (1, 3, 4, 14)
Prefer 1- and 2-segment couple configurations



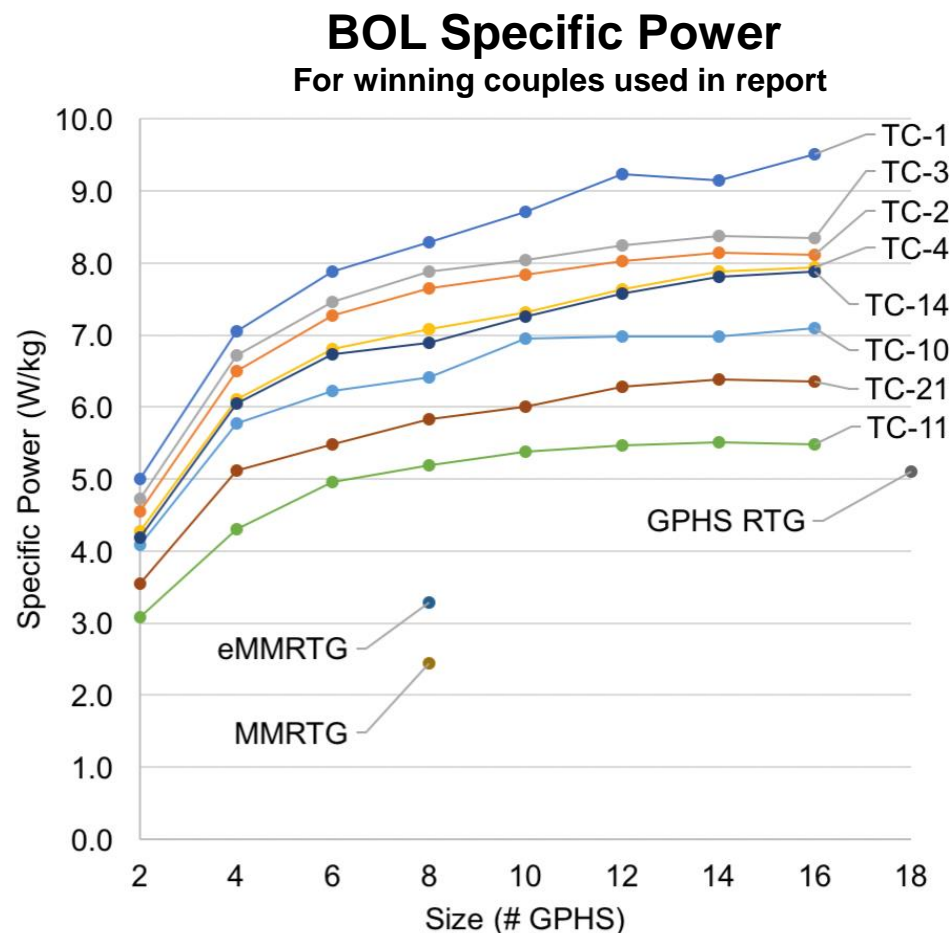
Concepts

- **3 surviving Types** of *Next-Gen* RTG Concepts:
 - Vacuum Only
 - Single-point design using single couple technology
 - Modular design using multicouple technology
 - Vacuum and Atmosphere
 - Hybrid
- **Variants: 2, 4, 6, 8, 10, 12, 14, and 16 GPHS** variants



Specific Power

- Figure displays the **BOL specific power** estimates for the modular concepts, in W/kg , for the various size options of each TEC selection.
- Nearly all options exceed** the specific power of both **the MMRTG and eMMRTG**
- The greater power output of the larger configurations may eliminate the need for multiple RTGs on certain missions, saving significant mass and fuel resources.
- The specific power of a generator increases with the number of GPHS used, demonstrating that **a single larger NG-RTG is more mass efficient than multiple smaller NG-RTG concepts.**



Summary Recommendation

- Next-Generation RTG baseline design decisions:
 - **Vacuum-only**
 - **Modular**
 - **16 GPHS (largest RTG variant)**
 - **$P_{\text{BOM}} = 400\text{-}500\text{ W}_e$ (largest RTG variant)**
 - **Mass goal of $< 60\text{ kg}$ (largest RTG variant)**
 - **Degradation rate $< 1.9\%$ per yr on average and including fuel degradation**
- System designed to be upgraded with new TC's as technology matures

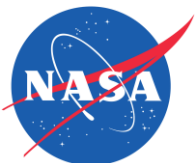


A Sea-change

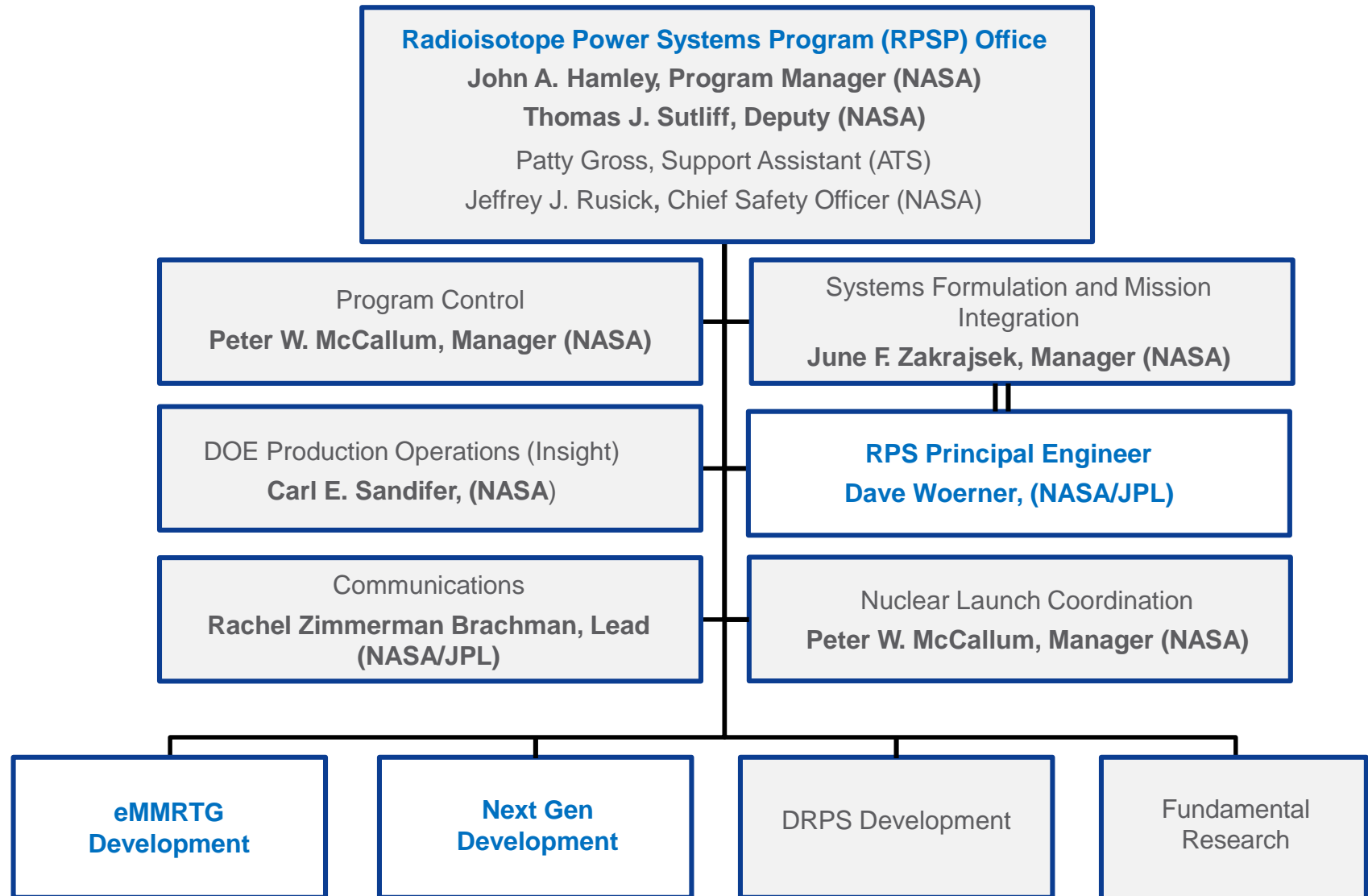
/ˈsē ˌCHānj/

noun

1. a profound or notable transformation.



RPS Program New Organization



Development Framework

The future

RTG	Converter Couple Technology	System Integrator	JPL role	Where is the Tech now?
MHW-RTG DOE Funded	Si-Ge unicouple from RCA	GE Astrospace (now LMA)	Converter Tech SE, V&V, LPP	Not available
GPHS-RTG DOE Funded	RCA Si-Ge tech transferred to GE Astrospace	GE Astrospace (now LMA)	Converter Tech SE, V&V, LPP	Not available
MMRTG NASA Funded	PbTe/TAGS couples at TESI, based on previous SNAP RTG Tech by TESI	Aerojet Rocketdyne (AR) assisted by TESI	Converter Tech SE, V&V, LPP	Current only “off-the-shelf” Tech
eMMRTG NASA Funded	SKD couple tech at JPL transferred to TESI	Aerojet Rocketdyne (AR) assisted by TESI	Tech transfer & maturation, Converter Tech SE, V&V, LPP	In Tech Maturation phase , led by NASA/JPL (TTDP) ; Potential transition to DOE-led flight system development phase in FY19
Next-Gen RTG NASA Funded	Segmented TE tech at JPL to be transferred to industry (competed/directed)	Unknown	Tech transfer & maturation, Converter Tech SE, V&V, LPP	In Tech Advancement phase , led by NASA/JPL (TTDP) ; Potential transition to Tech Maturation phase in FY20, DOE-led flight system development phase in FY23

Past

Future

Past implementation: technology was located at **Industry**

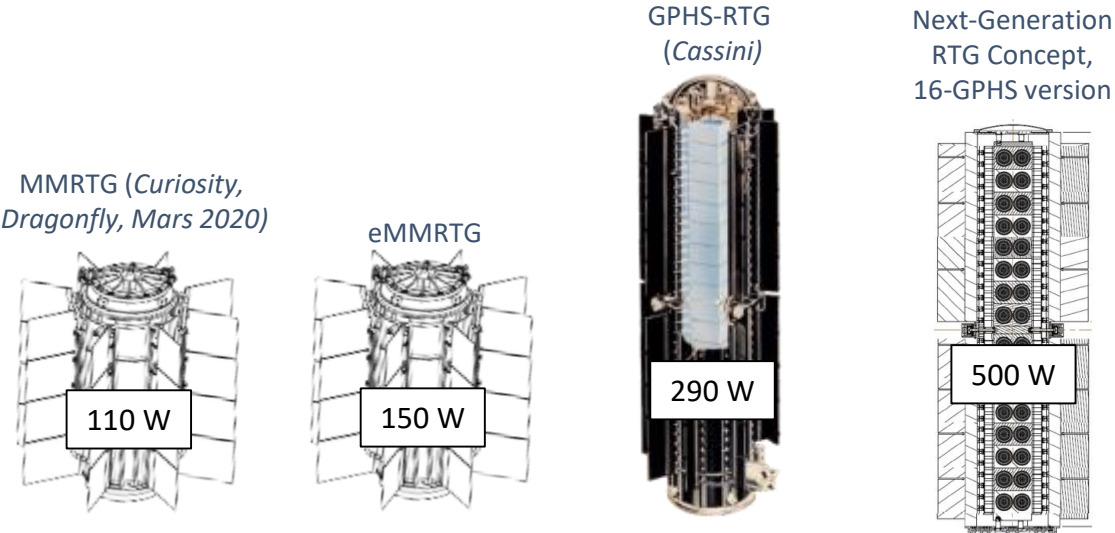
New implementation: technology located at **NASA/JPL**

Summary of Current Schedules and Status

- eMMRTG
 - Almost 6 years of technology maturation complete
 - Project instantiated, January 2018
 - 7 months to next technology decision gate review
 - Complete technology transfer to industry/begin development of qualification generator: 2019
 - Deliver qualification unit, unfueled: 2024
- Next-Generation RTG
 - Project instantiated, March 2018
 - Initiated TEC maturation for NG-RTG
 - Begin development of engineering unit generator: 2022
 - Complete technology transfer to industry: 2023
 - Begin development of qualification generator: 2024
 - Deliver qualification unit, unfueled: 2028



RTG Comparison



Power, launch, W	110	150	290 (880)	500
Power, end of life, W	55	91	213 (640)	362
Degradation rate, average	4.8%	2.5%	1.9%	1.9%
Design Life, years	17	17	18	17
# GPHSs	8	8	18	16
Length, m	0.69	0.69	1.14	1.04
Mass, kg	45	44	57	62

Largest variant would be expected to have higher maximum power output, more efficient use of fuel, and a low degradation rate compared with previous RTGs



New thermoelectric materials and technologies and RTG designs are being engineered for potential use on deep space missions for the first time in ~50 years.

It is a spectacular time to be working on thermoelectrics and RTGs

Thank you.

The Final Report of the Next-Generation RTG Study is here:

<https://rps.nasa.gov/resources/73/next-generation-rtg-study-final-report/?category=reports>





Jet Propulsion Laboratory
California Institute of Technology

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California Institute of Technology, under a contract to the
National Aeronautics and Space Administration.